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Nematofauna in Agroecosystems: A Review of their Ecological Significance and Response to Land Use

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Abstract

The study of biodiversity in soils, whether used for agricultural purposes or not, represents a promising area for ecological research. Agroecosystems are typically established as monocultures, and the associated practices lead to modifications in the soil microbiota structure, including nematodes. Nematodes are widely distributed organisms in the soil, exhibiting a great diversity of species and feeding habits. Due to differences in life cycles, reproductive rates, and persistence capabilities among members of these groups, nematode communities are being extensively studied using trophic structure and taxonomy data as biological indicators to measure changes resulting from the adoption of ecosystem-specific management practices, such as organic matter decomposition and nutrient cycling. Agricultural exploitation tends to favor nematodes that can survive and reproduce in environments subjected to frequent disturbances, particularly certain plant-parasitic nematodes, which, with increasing populations in the soil, can lead to phytosanitary issues. Therefore, the objective of this review is to report on studies conducted regarding the use of nematodes as bioindicators of land use worldwide, as well as research carried out in Brazil, which has vast land areas and diverse agroecosystems. Understanding the soil nematofauna, along with its trophic diversity and how it can be utilized as an indicator of healthy soil use, is of great value for the adoption of management practices and the consequent increase in agricultural production.

Keywords: Bioindicators, nematode community, ecological indices, soil health.

Soil fauna, including nematodes, has been used as an indicator of soil quality in agroecosystems due to its high sensitivity and ability to reflect the effects of soil management (BENINTENDE et al., 2008; KASCHUK et al., 2011). Nematodes are often regarded solely as pathogens when their population densities become very high, leading to significant yield losses.

However, only about 10% of nematode species cause damage to plants. Several nematode species have potential to be used as biological indicators of soil quality. Therefore, understanding farmers' knowledge and use of bioindicator organisms is important to promote sustainable management practices that do not lead to imbalances in soil biodiversity (MOURA; FRANZENER, 2017).

Community diversity studies are based on both qualitative data (taxonomic identification) and quantitative data (density or number of individuals per taxon, i.e., abundance). The frequency of occurrence of a given taxon is defined as the ratio between the number of samples in which the taxon was present and the total number of samples collected. The importance of a particular taxon is a measure that incorporates both abundance and frequency data. Mathematical indices can be used to quantify diversity, with the most common being the Shannon-Weaver index and the evenness index, the latter expressing the uniformity in abundance among different taxonomic groups within a community (NORTON, 1978; ODUM, 1988; SHANNON; WEAVER, 1949; SILVEIRA NETO et al., 1976; SOUTHWOOD, 1968). To compare communities between two areas or vegetation cover types, similarity indices such as those proposed by Jaccard and Bray-Curtis can be applied (BRAY; CURTIS, 1957; NORTON, 1978).

Soil nematode communities comprise five main trophic groups, classified according to their feeding habits: bacterivores (BF), fungivores (FF), omnivores (OM), predators (PR), and plant parasites (PP). The morphology of the nematode's anterior region and buccal cavity is closely associated with its specific feeding behavior (FERRAZ; BROWN, 2016).

Relative abundance data (%) of nematodes from each trophic group are useful for community studies of these organisms and for understanding their interactions with other members of the soil biota. Additionally, a trophic diversity index can be applied to study relationships among organisms (FRECKMAN; ETTEMA, 1993).

A maturity index was proposed by BONGERS (1990) as an indicator of the ecological succession stage of a nematode community and as a measure of environmental disturbance. To calculate this index, nematodes are classified as "colonizers" or "r-strategists" when they exhibit rapid population growth under favorable conditions, short life cycles, high colonization ability, and greater tolerance to environmental disturbances. In contrast, "persisters" or "k-strategists" are characterized by low reproductive rates, long life cycles, limited colonization capacity, and higher sensitivity to environmental changes. These ecological characteristics were used to create a c-p (colonizer- persister) scale, ranging from 1 to 5, where values closer to 1 are associated with colonizers and values closer to 5 with persisters. The c-p values are used to calculate the maturity index, which is a weighted average based on the relative abundances of these nematodes. This index considers only free-living nematodes, excluding plant-parasitic ones. A separate plant parasitic index can be calculated using the same method, but based solely on plant-parasitic nematodes (BONGERS, 1990). In 1994, Yeates proposed an adaptation of the maturity index that includes all trophic groups.

To simplify the calculations required for ecological indices, SIERIEBRIENNIKOV et al. (2014) developed NINJA (Nematode Indicator Joint Analysis), an online platform based on the R language that automates the calculation of indices related to ecological maturity, trophic structure, and food web analysis. The platform is free, user-friendly, and accelerates the calculation process. Regarding diversity indices, there are already many software tools available for such analyses, including PRIMER (CLARKE; GORLEY, 2006), which also allows for hierarchical classifications based on the similarity or dissimilarity of nematode communities.

Until the 1970s, studies on nematode diversity that considered all taxonomic and trophic groups occurring in soils were scarce. Most research at the time was limited to species occurrence lists or broader taxonomic categories, along with general field-based observations (NORTON, 1978). After 1980, the number of studies on this topic increased, with more in-depth investigations being conducted. These studies began to apply established ecological research methods for characterizing communities, including the use of mathematical indices and statistical analyses (GOURLAT, 2007).

The study of soil biodiversity, whether in agricultural or non-agricultural systems, has gained increasing importance in ecological research. Agroecosystems are typically established as monocultures, and the practices associated with them often lead to modifications in soil structure compared to uncultivated areas. These changes result in habitat instability, which can inhibit the establishment and persistence of certain nematode groups. Agricultural activities tend to favor nematodes that are able to survive and reproduce in environments subjected to frequent disturbances, including fluctuations in food availability. As a result, nematode communities in agroecosystems generally show lower diversity when compared to natural areas (NORTON; NIBLACK, 1991).

Studies conducted across various geographic regions around the world have reported significant changes in the composition of soil nematode communities over time, as native ecosystems are progressively replaced by other types of vegetation, primarily for agricultural purposes (BONGERS, 1990; COLEMAN et al. 1991; FRECKMAN; ETTEMA, 1993; NEHER, 2001).

One of the first reported studies on the topic was conducted in the 1950s by ZAMITH AND LORDELLO (1957), who observed that soil samples from the State of São Paulo, Brazil, exhibited a greater number of nematode genera and species in undisturbed or minimally disturbed soils. They concluded that when agricultural cultivation is introduced in areas with native vegetation, there is a gradual elimination of some taxa, the persistence of others, and even the introduction of new ones through contaminated plant material or agricultural machinery. Consequently, this review aims to present the evolution of studies concerning the use of nematodes as indicators of soil use. Numerous and significant experiments conducted in different agroecosystems and natural vegetation areas are listed in chronological order and grouped into two categories: the first covering studies conducted in foreign countries, and the second describing experiments carried out in Brazil, reflecting its vast ecosystems and the diversity of soil use and management practices.

In India, LAL et al. (1983) demonstrated that burning of native vegetation followed by plowing to open new areas for agricultural production led to a decrease in local populations of plant-parasitic nematodes. However, over time, with the establishment of different crop types, the authors observed an increase in the multiplication of various taxa of plant-parasitic nematodes. Nevertheless, the cultivation of *Crotalaria juncea* L. showed adverse effects on several of these taxa and favored the proliferation of several genera of microbivorous, predatory, and omnivorous nematodes.

In the United States, FRECKMAN; ETTEMA (1993) studied nematode communities in natural ecosystems and agroecosystems employing annual crop rotation (corn/soybean/wheat) with varying levels of anthropogenic intervention. They concluded that natural systems had the highest values for taxon richness and diversity. Bacterivorous nematodes predominated across all areas, while fungivores were more prevalent in native vegetation, and plant-parasitic nematodes were less abundant in organic cropping areas. Predators and omnivores were the least abundant trophic groups in the sampled areas.

In the Czech Republic, a comparative study was conducted on nematode communities in areas under wheat/potato rotation, fallow fields after maize cultivation, forest, and natural grassland. High values for diversity and maturity indices were mainly observed in the forest and grassland areas, indicating that these communities were more stable and less disturbed (HÁNEL, 1995).

In Australia, nematode communities in native and cultivated pastures were compared. The replacement of native pastures and the regular application of fertilizers for pasture maintenance led to changes in nematode fauna (in terms of taxonomic composition and abundance). Total nematode abundance increased under cultivation, primarily due to the proliferation of bacterivorous nematodes, which, according to the authors, indicated improved quality of plant residues as a food source for the soil microbiota, especially bacteria. However, the abundance of predatory nematodes and the maturity index were lower in cultivated pastures (YEATES; KING, 1997).

In Côte d'Ivoire, plant-parasitic nematode populations were studied in native forests and in rice crops established after partial forest clearing (COYNE et al., 1999). The immediate effect of forest clearing on nematode diversity was minimal, but successive rice plantings led to rapid and significant changes in both trophic and taxonomic structures, with a decrease in overall diversity and the dominance of a few plant-parasitic species.

In the United States, NEHER (1999) compared trophic diversity and maturity indices of soil nematode communities in five agricultural production areas managed under two conventional systems: one using both chemical and organic inputs, and the other without chemical inputs. The crops grown in these areas included cereals and vegetables. The ecological indices used generally did not allow for clear differentiation between nematode communities from the two management systems. The author concluded that, contrary to common assumptions, organically managed soils should not always be considered suitable reference environments for comparative assessments of biological soil quality across different systems.

In Slovakia, three systems were compared regarding the structure of their nematode communities: arable field, permanent pasture, and newly established pasture. Plant-parasitic nematodes were the most prevalent in all environments studied, followed by fungivores in the newly established pasture and omnivores in the arable field and permanent pasture. The nematode communities in the arable field and permanent pasture were structurally similar, while differing from that of the newly established pasture (CEREVKOVÁ, 2006).

In Uruguay, nematode community structures were observed in rice monoculture, cultivated pasture under rotation, and natural grassland. In both the rice field and the rotational pasture, bacterivorous nematodes were the most abundant. In the natural grassland, fungivores, plant-parasitic nematodes, and predators were respectively more abundant. No predatory nematodes were found in the rice monoculture system. Taxon richness and diversity indices clearly differentiated the two pasture systems from the rice monoculture (KORENKO; SCHMIDT, 2007).

CESARZ et al. (2018) analyzed the effect of soil carbon dioxide (CO_2) emissions following nitrogen addition in pastures on the diversity of soil nematodes, using maturity indices and trophic guilds as bioindicators. They found that nitrogen addition led to an increase in fungivorous nematode density, which correlated with elevated CO_2 emissions. Plant-parasitic nematodes from the Longidoridae family were reduced with nitrogen addition and subsequent CO_2 increase, although other plant parasites and omnivores were not significantly affected. The results suggest a compositional shift in the community, from bacterivores to fungivores, under high nitrogen conditions.

YAN et al. (2018) investigated the effects of drought, under controlled conditions, on soil nematode communities in wheat cultivation. A total of 32 nematode genera from 18 families were identified across four experimental treatments, including 13 bacterivores, 10 plant parasites, 4 fungivores, and 5 predators/omnivores. The number of genera and overall diversity were significantly lower under drought treatments, with *Helicotylenchus* and *Eucephalobus* being the dominant genera. Prolonged drought caused degradation of the nematode community, resulting in a reduction of trophic structure within the agroecosystem.

HABTEWELD et al. (2022) evaluated four carrot-producing fields in the United States. *Pratylenchus* was the predominant plant-parasitic nematode genus in all study sites. Despite this, decomposition chain analysis indicated that two of the fields exhibited low to moderate levels of soil disturbance, suggesting a relatively favorable soil-use condition.

POTHULA et al. (2022) assessed soil disturbance levels based on nematode abundance and richness in different management systems in the United States. Four treatments were analyzed: a forest ecosystem considered an undisturbed control, litter not removed, litter removed, and a tilled area used for monoculture. The cultivated area significantly reduced overall nematode abundance, with bacterivores, predators, and omnivores being the most affected trophic groups. Genera such as *Acrobeles*, *Aporcelaimellus*, and *Boleodorus* declined significantly under minimal soil disturbance treatments, such as surface litter removal. Regarding c-p (colonizer–persister) values, *Dorylaimida*, *Aporcelaimellus*, *Alaimus*, *Clarkus*, and *Tripyla* were most sensitive to disturbance. Even some bacterivorous nematodes—typically considered tolerant to agricultural ecosystem changes—were sensitive to disturbance in this study, including *Clarkus*, *Filenchus*, and *Plectus.*

INÁCIO et al. (2022), in the Ribatejo region of Portugal, studied various soil management types, mainly promoting the use of cover crops to improve soil structure and properties and enhance nutrient cycling. Nematode communities were assessed in soils under three different treatments with plant cover mixtures: grasses and legumes, annual ryegrass, and forage radish, along with a control (no cover crop). After four years, the number of free-living nematodes increased in all treatments except the control. Bacterivorous nematodes were the most prominent group, indicating improved soil organic matter content.

TITO; MEDINA (2023) analyzed nematode communities in relation to different crop types (pasture, maize, fig, eucalyptus), soil parameters, agrochemical use, and heavy metal content in a mining community in Peru. Using multivariate analysis, the authors found significant correlations during the rainy season: *Helicotylenchus* was associated with vanadium, and *Globodera* with titanium. In the dry season, *Meloidogyne* was correlated with vanadium and *Hemicycliophora* with lead. Abiotic stress negatively affected bacterivorous, fungivorous, and phytophagous nematodes. Omnivores and predators were unaffected, suggesting they may serve as reliable bioindicators under such conditions.

In Brazil, nematological studies began in the 1990s, initially focusing on the classification of plant-parasitic nematodes. Research conducted in the States of Goiás, Minas Gerais, and the Federal District studied the diversity of plant-parasitic nematodes, down to the genus level, based on samples taken from riparian forests, perennial crops, and annual crops. Representatives of nematodes from the Criconematoidea, Aguinidae, and Tylenchidae groups, which are very common in native vegetation areas, had their populations reduced to undetectable levels in areas replaced by crops. *Pratylenchus* and *Ditylenchus*, on the other hand, were only observed in cultivated areas (CARES; HUANG, 1991).

Another study in the Central Region of Brazil, including the Federal District and adjacent regions, conducted by Huang and Cares (1995), also explored the taxonomic diversity of plant- parasitic nematodes occurring in areas with three types of native vegetation (Riparian Forest, Cerrado, and Cerradão) and cultivated areas (annual and perennial crops). The authors concluded that the taxonomic diversity of nematodes paralleled the botanical diversity of the studied environments, with the Cerrado and Cerradão showing the highest plant diversity. The abundance of plant-parasitic nematodes was higher in perennial crop areas, likely due to the large root biomass of these crops compared to annual crops.

Starting in the 2000s, studies began to be developed in Brazil characterizing the nematode community present in the soil, involving different trophic groups. Thus, GOMES et al. (2003) described the soil nematode community in soybean cultivation in the Cerrado biome. The author noted that the evaluated system was dominated by plant-parasitic genera such as *Helicotylenchus*, *Meloidogyne*, and *Pratylenchus*, as well as bacterivorous genera like *Acrobeles* and *Cephalobus*. In this same study, the author observed that mycophagous nematodes were more abundant at the end of the crop cycle, a period of high decomposition due to microorganism activity, especially fungi. However, the abundance of mycophagous nematodes decreased after the end of the crop cycle, likely due to the absence of substrates for fungal decomposition. Furthermore, an increase in the abundance of bacterivorous nematodes was observed after the rainy season began, with a subsequent decrease in the dry period.

In São Carlos, in the State of São Paulo, nematode communities from three different ecosystems were studied: one of natural vegetation in the Cerrado and two agricultural crops, guava and irrigated corn, both in the Cerrado, with samples taken in two different seasons (GOULART; FERRAZ, 2003; GOULART et al., 2003). The occupation of the Cerrado with crops significantly affected the composition of the nematode communities, resulting in a reduction in the relative abundance of predatory or omnivorous forms and a lower overall trophic diversity. No clear predominance of colonizing or persistent nematodes was detected in the studied areas. In crop areas, Criconematoidea taxa were less abundant than in the Cerrado, with the absence of *Discocriconemella*, while genera like *Pratylenchus* and *Helicotylenchus* occurred in high abundances.

MATTOS et al. (2006), in a study involving a larger number of agroecosystems, characterized four types of native vegetation and four types of agricultural crops in the municipalities of Cristalina, Luziânia, and Padre Bernardo, in the State of Goiás. These included: Cerrado, Cerradão, Gallery Forest, native grass land, coffee, eucalyptus, corn, and tomato. The highest nematode abundance values were found in the annual crops of corn and tomato, while the lowest values were found in eucalyptus. The genus richness was higher in Cerrado vegetation and lower in the tomato crop. In native vegetation, families like Tylenchulidae, Tylenchidae, Criconematidae, Hoplolaimidae, and Cephalobidae were prevalent. In cultivated areas, the prevalent families were Cephalobidae, Hoplolaimidae, Panagrolaimidae, Rhabditidae, and Heteroderidae. In most cultivated areas, bacterivorous nematodes dominated, while predators and omnivores were minority groups in all types of ecosystems. In native vegetation and corn crops, plant-parasitic nematodes prevailed. Omnivores presented the highest relative abundances in native vegetation, eucalyptus, and coffee. The highest relative abundance of the Criconematoidea superfamily was found in native vegetation. Key genera that best distinguished between areas were Trophotylenchus and Discocriconemella. The genus *Trophotylenchus* showed high abundances in all native vegetation areas, distinguishing them from others. *Discocriconemella* exhibited high abundances in Cerrado and Cerradão, distinguishing these areas from others.

TORRES et al. (2006), in Baraúnas in the State of Rio Grande do Norte, studied the structure of nematode communities in areas used for melon (*Cucumis melo* L.) cultivation. The areas had previously been used for cotton cultivation and had been left without agronomic use for a decade. The sampled areas were divided into those with and without symptoms of nematode damage. Both areas showed diversity indices with low values, reflecting the high level of disturbance caused by the long monoculture of cotton. The period the areas spent without agronomic use was not enough to restore the balance of the nematofauna, with a low relative abundance of omnivores and predators.

SILVA et al. (2008a) studied the diversity of plant-parasitic nematodes in native areas of the Amazon Rainforest, comparing them with areas occupied by teak (*Tectona grandis*) and pasture (*Brachiaria brizantha*) in State of Mato Grosso. Fourteen plant-parasitic nematode taxa were identified, with *Xiphinema luci* being reported for the first time in Brazil. These taxa, especially those from areas with primary vegetation, belong to families with various parasitism modes. The authors report that the prevalence of these taxa is likely due to the great plant diversity of the Amazon biome. The comparison between the areas revealed low similarity between the two preservation areas, probably reflecting the endemism of plant species. When areas with primary vegetation and adjacent cultivated areas were compared, no similarity was found, showing the influence of agricultural activity on the composition of the plant-parasitic nematode community.

SILVA et al. (2008b) conducted a study on the plant-parasitic nematode fauna in three locations in the São Paulo State Atlantic Forest in the municipalities of Cananéia and Pariquera-Açu, covered with ombrophilous forest and restinga vegetation. A total of 17 taxa were identified. *Dolichodorus miradvulvus* and *Throphurus lomus* were reported for the first time in Brazil. The families with the greatest species richness were Hoplolaimidae and Criconematidae. In addition to these, the family Tylenchulidae represented the highest abundance of individuals. The genera *Helicotylemchus*, *Aorolaimus*, and *Trophotylenchulus* were the most abundant. The reduced species richness may be related to the polyphagous nature of these nematodes. The high similarity between the studied areas can be attributed to the stability of the environment. The authors highlight the absence of *Meloidogyne javanica* and *Radopholus similis*, the nematodes that cause the most agricultural damage in the Vale do Ribeira, indicating that management in the region should focus on preventive measures.

TOMAZINI et al. (2008 a, b) studied the taxonomic and trophic structure by determining the maturity indices of nematode communities in preserved natural forest areas and perennial (banana, citrus, and peach) and annual (corn and legumes) crops in rotation in the municipality of Piracicaba in the State of São Paulo. Soil samples were collected in two seasons (rainy and dry) and at two depths (0-15 and 15-30 cm). The nematodes were identified at the genus level, and abundances, diversity indicators, and maturity indices were calculated. In total, 61 genera from 32 families were assimilated. The total abundances were higher at the shallower depth in both sampling seasons. The highest genus richness values at the shallower depth were in the forest area, but at the deeper depth, areas with annual crops and citrus stood out. The authors noted that the Shannon-Weaver and Simpson diversity indices were less effective than genus number and richness in discriminating between the studied systems. Plant-parasitic nematodes were the predominant trophic group in all evaluated systems, followed, in general, by bacterivores. The maturity index, modified maturity index, and plant- parasitic nematode index indicated fewer disturbances in the forest and citrus orchard areas.

MONDINO et al. (2009) studied the effect on the nematode community in an area of the Integrated Agroecological Production System in the municipality of Seropédica in the State of Rio de Janeiro. The treatments consisted of different crops: pineapple, beans, maize/bean consortium, arrowroot, pasture, and capoeira. Twenty-one nematode genera were reported, with 79% being plant-parasitic, 14.5% bacterivores, 4.7% omnivorous-predators, and 1.1% mycophagous. Using the Shannon index, equitability, and maturity index, the area with arrowroot was considered to have the best agroecological conditions in the study.

SANTIAGO et al. (2012) studied soil nematodes are sensitive to human intervention and widely used as biological indicators of disruptions and alterations in soil quality. The aim of this work was to identify nematodes that are good biological indicators in maize crops under different management systems, and to establish the impact levels of these systems. Soil samples were collected over a 3-year period at a depth of 0.0-0.3 m in areas under six different management systems for maize (*Zea mays*) monoculture, and intercropped maize and *Canavalia ensiformis*. Six areas of native vegetation were also assessed to provide a reference for ecological balance. After identification and counting, nematode communities were characterised according to abundance (total and relative), diversity (identified genera and diversity indexes), trophic structure and ecological maturity (disturbance indexes). Nematodes proved to be good ecological indicators, responding to the systems employed. Intercropping maize and *Canavalia ensiformis* in at least one assessment year reduced disruption and increased nematode diversity, which were both verified based on specific indexes. It was also observed that the maize monoculture increased disruption leading to a drop in nematode fauna diversity and an increase in the incidence of plant-feeding nematodes.

ARIEIRA et al. (2013) evaluated the effect of continuous sugarcane cultivation on plant-parasitic nematodes and free-living nematodes. The nematodes were extracted from soil samples collected from native vegetation areas and agricultural plots in two municipalities in Paraná State. The nematodes were identified and analyzed by trophic groups. The duration of sugarcane cultivation severely affected the structure of the communities, with an increase in the abundance of plant- parasitic nematodes as cultivation time increased. The agricultural plots were dominated by *Pratylenchus* spp. and *Helicotylenchus* spp., while the communities in native vegetation areas were dominated by free-living nematodes, mainly bacterivores, with the presence of omnivores/predators and *Mesocriconema* sp..

CARDOSO et al. (2015) studied 12 sugarcane cultivation areas and 13 remaining rainforest areas in sugarcane regions of Pernambuco State. Edaphic factors and agricultural management were related to the nematode community in the studied areas. Eighteen genera were identified, with 11 found in all areas of the study. The composition and structure of the nematode communities differed between the studied environments. The genus *Pratylenchus* and *Hoplolaimus* predominated in areas intensely and non-intensely cultivated with sugarcane, respectively. On the other hand, Dorylaimida predominated in forest soils.

COUTINHO et al. (2018) used nematodes as bioindicators of disturbance in an Integrated Crop- Livestock-Forest area, in a long-term experiment in the municipality of Sinop in the State of Mato Grosso. Ten treatments were analyzed: 1- Control corresponding to the forest and spontaneous vegetation area; 2- Crop with rotation between soybean/corn/corn off-season; 3- Livestock, with use of *Brachiaria brizantha*; 4- Integrated Crop-Livestock; 5- Integrated Livestock-Crop; 6- Integrated Crop-Forest; 7- Integrated Livestock-Forest; 8- Integrated Crop-Livestock-Forest; 9- Integrated Crop-Livestock-Forest; and 10- Integrated Crop-Livestock-Forest. Two sampling periods were conducted: the first before cultivation and the second at the end of the soybean cycle. Plant-parasitic nematodes dominated both sampling periods. With the implementation of the systems, fungivores and bacterivores were reduced. Predatory nematodes had a greater number of genera found in the second collection. Omnivores were little affected in treatments 1, 5, and 9. The highest diversity and maturity indices of the nematode communities were reported in systems 1, 7, and 9, with the Integrated Crop-Livestock-Forest system showing an increase in diversity indices, while the crop system caused the greatest disturbance.

CAIXETA et al. (2016) studied the nematode community in four systems to assess the impact of mining in the municipality of Sabará in the State of Minas Gerais. The areas evaluated were: tropical forest, savanna, eucalyptus cultivation, and pasture. A total of 16 genera and 13 families were identified. The calculated indices, genus number, Margalef index, and Maturity index significantly differentiated the pasture system from the others. Furthermore, the exposure of soil in the pasture negatively influenced the composition of the trophic chain, mainly of nematodes with high c-p values from the maturity index. Among the soil properties analyzed, pH strongly influenced the distribution of nematodes, negatively affecting the abundance of all c-p groups and the diversity of nematodes.

However, pH positively affected the trophic groups of fungivores and plant-parasitic nematodes. There was similarity between the tropical forest and savanna systems with the eucalyptus cultivation area, suggesting that the adopted cultivation practice seems to be suitable for promoting the recovery of areas subjected to mining practices.

SILVA et al. (2020) investigated different types of land use, the effect of soil properties, and climatic variables on the community structure and ecosystem function of nematodes in the Caatinga, at the Catimbau National Park in Pernanbuco State. The main agricultural activities in the region are goat and cattle farming and subsistence agriculture. In the first stage, the effect of soil properties, precipitation, and temperature on the nematode community was analyzed. The studied areas were natural forest, agricultural land, and secondary forest. The results demonstrated that the conversion of native Caatinga vegetation into cultivation systems negatively affected the nematode community, reducing the total abundance of bacterivores and predators/omnivores. Soil properties and climatic variables affected the taxonomic composition of nematodes. The seasonal effect (dry and rainy season) on the nematode community was analyzed by calculating the abundance, carbon biomass, and metabolic footprint of each guild and nutrient cycling function. It was found that the conversion of native Caatinga vegetation into cultivation systems decreased soil fertility, carbon biomass, metabolic footprint, and the ecosystem function of nematodes. The rainy period favored the functional guilds of nematodes.

VIEIRA JÚNIOR et al. (2021) studied the soil nematode community in coffee tillage in agroforestry systems in the municipality of Araponga in the State of Minas Gerais. The treatments were: organic coffee with poultry bedding manure; organic coffee with bovine manure; natural coffee with plant residue fertilization; natural coffee with forest litter fertilization; and control, a forest fragment located near the plantations. The study found no significant difference in total abundance and in the values of Shannon and Simpson indices.

The most abundant trophic groups in natural coffee and forest areas were plant-parasitic nematodes. Coffee plantations fertilized with poultry bedding and bovine manure showed a higher abundance of bacterivorous nematodes and maturity index values close to those found in the forest area. Thus, the author emphasizes that fertilization does not affect the abundance and diversity of genera but influences the abundance of trophic groups. Agroforestry and organic coffee plantations fertilized with poultry bedding and bovine manure showed low anthropogenic disturbance, and the natural coffee plantation, under plant fertilization, resembled the studied forest fragment.

CAIXETA et al. (2023) analyzed changes in nematode communities in four different land use types in the submedian region of the São Francisco River Valley in the State of Pernanbuco. The studied areas were natural vegetation (Caatinga), natural area with salt accumulation, agricultural cultivation areas with cover crops for pastures (*Cenchrus echinatus*, *Ficus carica*, *Leucaena leucocephala*, and *Gliricidia sepium*), and fruit areas (*banana*, *mango*, *grapevine*, and *guava*). Forty-two genera from 23 nematode families were identified. The abundance, diversity, and maturity indices were higher in the natural vegetation system and lower in the area with salt accumulation. Bacterivores, omnivores associated with predators, and plant parasites were the trophic groups most affected by land use type. In general, except for the natural vegetation area, the manipulation and type of agricultural land use significantly influenced the composition of soil nematode communities in the São Francisco River Valley.

It is worth emphasizing that for the studies described here, the use of classical taxonomy through light microscopy is extremely important. Minimal knowledge of nematodes is used in these studies, as both external and internal anatomy are directly related to their functional characteristics, especially when studies are related to the diversity and trophic groups of nematode communities. Therefore, nematodes are considered difficult to identify due to their small size and challenges in observing key characteristics for identification under a conventional light microscope. Morphological differences are often relatively small and require considerable knowledge of taxonomy for accurate classification (OLIVEIRA et al., 2012). Furthermore, there are few nematologists trained in classical taxonomy, and it is even rarer to find professionals studying all the groups of free-living nematodes, not just those considered plant pathogens.

A study with the aim of evaluating and comparing two evaluation methods was conducted by SCHENK et al. (2020), who analyzed the nematode community in river sediments to detect pollution levels. In this study, the authors compared two techniques for identifying nematodes. The first used classical taxonomy through light microscopy, and the second used molecular techniques called metabarcoding. In the molecular analyses, 200 individuals from each collected sample were subjected to DNA extraction and PCR reaction with fragments of the 28S rDNA, 18S rDNA, and cytochrome oxidase I (COI) genes. For data analysis, the NemaSPEAR [%] index, a specific index for nematodes that assesses sediment quality and can detect chemical pollution, was used. The objective of the study was to apply the NemaSPEAR [%] index to the data generated by molecular analysis and validate the results by comparing them with those obtained through classical taxonomy and microscopy. A total of 123 species were identified through classical taxonomy, of which only 36 species were detected molecularly. Of the 25 most common species detected by each method, 9 species were detected both morphologically and molecularly. It was found that some species were detected by both methods, seven by morphology and 28S rDNA analysis; four by morphology and 18S rDNA analysis; and two by morphology and both 18S and 28S rDNA analysis. Among the 12 dominant species identified by morphology, six were not detected using the molecular approach. When the results were analyzed considering nematode genera, 80 genera were identified by morphology, of which 39 were identified by at least one molecular marker. Among the 25 most abundant genera identified morphologically, 17 were also detected using metabarcoding, and five were found by all methods used (morphological, 28S rDNA, and 18S rDNA). Among the most common genera identified by morphology, *Filenchus*, for example, was not detected by molecular methods. The authors concluded that the results based on molecular studies were worse than those based on morphology in the investigated locations. However, when the results evaluated only the genera of nematodes, there was a positive correlation between the data obtained through morphological and molecular analyses. One possibility for this difference, according to the authors, may be attributed to the lack of species-level records in genomic databases for comparison. However, the authors mention the need for future studies to validate this approach and to evaluate mass extractions of entire communities for assessments using only molecular methods.

Even with significant advances, the science of using soil-dwelling nematodes as bioindicators is still progressing and will continue to develop as an important area of research in nematology. As new data and studies accumulate, particularly aiming at understanding free-living nematodes and their fundamental role in nutrient cycling, it is possible that nematologists will provide and enable the reliable application of nematodes as bioindicators across a wide range of agroecosystems. The reality is that the structure of the nematode community reflects the condition of the soil. Unhealthy soils are associated with the excessive use of chemical fertilizers and pesticides, especially in long-term monoculture systems. Soils are increasingly subject to degradation of their physical-chemical properties, reduced biodiversity, and low productivity. Soil nematodes are involved in nutrient cycling, energy transfer, and the soil carbon cycle. Increasing the abundance of bacteriophages and fungivores can enhance the decomposition of soil organisms and reduce the impacts of soil-borne pathogens due to their trophic structure. Reducing the abundance of plant-parasitic nematodes, especially those that cause damage to plants, can promote healthy plant growth. In addition, soil predators, which are sensitive to environmental changes, can be used to assess impacts, especially those caused by agroecosystems.

One of the main difficulties in conducting these studies is the correct classification of nematodes. Classical taxonomy is used in the vast majority of studies. Investments in skilled labor and the availability of classification keys and scientific literature are of great value for the proper identification of these organisms. However, combining classical techniques with modern methods, especially molecular biology techniques, can greatly enhance studies aimed at this purpose. It is important to emphasize that a comprehensive, integrated, and optimized set of approaches will be crucial to increasing crop productivity and improving soil nutritional quality, which will consequently reduce the damage caused by plant-parasitic nematode groups.

AUTHORSHIP CONTRIBUTION (CONTRIBUIÇÃO DE AUTORIA)

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Conceptualization (Lead); Investigation (Equal); Project administration (Equal); Supervision (Equal); Validation (Equal); Visualization (Equal); Writing - original draft (Lead); Writing - review & editing (Lead)

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AVAILABILITY OF DATA AND MATERIAL (declaração de disponibilidade de dados de pesquisa)

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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CONFLICTS OF INTEREST

All authors declare that they have no conflict of interest.

ETHICAL APPROVAL

Not applicable.

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